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Preferential Emissions Measurement Survey for National Gas

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Abstract

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Contents

Executive summary

This report presents the results of a fugitive emissions survey to the National Gas FutureGrid facility at DNV Spadeadam site. The measurements were carried out by NPL on 7th October 2025 and form the deliverables for the National Gas Transmissions Preferential Emissions Survey.

The results of this study are to assess, due to the physiochemical differences between hydrogen and methane, whether hydrogen, being a smaller molecule, is preferentially released from leaks within pressured pipework when in a hydrogen:hydrocarbon blend. Simultaneous measurements of the concentration of hydrogen and hydrocarbons were made at each leak such that the emission ratio of the gas concentration could be determined. Additionally, the emission rates of both gases were quantified simultaneously with the ratio of the rates calculated. The calculated emission ratios could then be compared to the source gas blend ratio.

The aim in this project was to revisit emission sources previously identified in January 2025 as part of a separate project. At that time the facility was running with 100% hydrogen as the process gas. The emission sources proposed for inclusion in this project took account of the reduced hydrogen content in the blended process gas and selected where they would be expected to be above the detection limit.

In total six emissions were measured with a percentage difference between the measured hydrogen:hydrocarbon leak rate ratio and the reported process gas ratio of -81 – 78%. Two leaks exhibited a greater proportion of hydrocarbon in the emitted gas than the reported blends with 4 exhibiting a greater proportion of hydrogen. For two of these leaks only a hydrogen emission rate was quantified although it should be noted that for both leaks both gases were measured during an initial screening of the component.

It was noted that there were challenges in achieving and maintaining the desired hydrogen and hydrocarbon gas ratio within the equipment and that there are potential issues with the mixing of the gases within the equipment. Differences in the measured gas ratio of emissions could arise from poor mixing within the equipment leading to

different internal ratios at the point of the leaks. The results from this study did not show a consistent preferential emission of one gas over the other from the blended process gas mix, however, the results are inconclusive with numerous challenges in the experimental design. Further work is required to determine whether preferential emissions are exhibited from industrial process equipment in which it will be necessary to fully characterise the internal gas composition in order to interpret the results.

1. Introduction

This report presents the results from a fugitive emissions survey for National Gas at the FutureGrid facility at DNV Spadeadam (NPL Reference: 2025030288). Simultaneous measurements of emissions hydrogen (H_2) and hydrocarbons (HC) were conducted to assess whether preferential emission of hydrogen (or HC) occurs from fugitive emissions when operating with a blended process gas.

A previous measurement survey at the FutureGrid facility in January 2025 identified 31 quantifiable emissions of hydrogen when the facility was operating on 100% hydrogen gas. In this study the facility was operated with a blended gas mixture of nominally 20:80 H_2:HC. NPL and National Gas selected 9 of the previously identified leaks for inclusion in this study with the intention that they cover a range of emission magnitudes. For each emission the source was screened to confirm the presence of emission and then the leak rate of both hydrogen and hydrocarbon quantified simultaneously using a high flow sampling technique.

2. Site description

The National Gas FutureGrid high-pressure test facility is located at the DNV Spadeadam site in Cumbria. The facility is built from decommissioned assets from the National Transmission System and is designed to replicate the UK gas transmission system. Whilst it is a test facility it can be deemed to be representative of the UK's gas transmission system infrastructure. Component types found onsite include flanges, valves, plugs, compression fittings, joins. Figure 1 shows an schematic of the FutureGrid site with the sampling locations for the internal composition (A,B,C), the location of the GC sampling point and the hydrogen inlet location highlighted. During the study the rig was first filled with hydrogen before introducing hydrocarbon.

Figure 1. Site map schematic of the FutureGrid test facility

3. Measurement approach

Measurement were taken between 12:57 and 14:51 on Tuesday 7th October 2025. Although the leaks had previously been identified the rig components in the immediate proximity of the previously identified leaks were screened again to document the magnitude of the leak and to offer measurements of the blend composition via detection methods before leak rate quantification.

3.1 Leak detection

The initial screening survey of the site was conducted using a Teledyne FLIR GMI Gasurveyor 700 Hydrogen instrument (GS-700 H_2). This instrument is a hand-held, battery-operated device capable of selectively measuring the concentration of hydrogen and hydrocarbon gases. An internal pump continuously draws sample into the instrument, and the hydrogen and hydrocarbon concentrations are measured. In this work, the CGI function of the instrument was selected so that total flammables were recorded, separated into the hydrogen and hydrocarbon component. The gas concentration measurements of both hydrogen and hydrocarbons were made simultaneously on the same sample ensuring the results are not affected by temporal or spatial differences in sampling.

Prior to starting the screening survey the GS-700 H_2 was calibrated using known concentrations of hydrogen gas. Hydrogen concentration values have been corrected for the calibration. A single point calibration check was conducted for the hydrocarbon measurement using methane gas. The instrument showed good agreement to the gas reference with a ~3% variability between repeats. Hydrocarbon measurements have not been corrected but a 3% uncertainty has been applied.

The specifications of the HETEK flow sampler state the sampling flow rate is accurate to within 5% of the recorded rate. A spot check of the sampling flow rate using a BIOS flow meter, showed a variability of ~1.3%. In this work the uncertainty of the sampling flow rate has not been included as the focus is on the ratio of the gases rather than the true magnitude. As the measurements of both gases are made simultaneously the sampling flow will be the same for both.

As these leaks were already known, screening of the components was to confirm the presence of the leak and to help determine the best approach for leak rate quantification. The hydrogen and hydrocarbon concentrations measured at this stage also allow an initial estimate of the leak ratio of the gases to be calculated although this is likely to be less accurate than that obtained during quantification. The probe was placed close to the leaking component, and as the GS-700 H_2 in CGI mode logs a reading every minute, the probe was kept in this position for 3 minutes as to ensure that data was logged. Videos of the GS-700 H_2 screen were taken, which allowed for simultaneous gas readings to be recorded, as a backup against data logging failure.

Previous testing on the GS-700 H_2 has identified an error condition where the instrument can report non-real concentration values. Such an error is easily identified as the reported values are binary multiples (e.g. 16,32,64) and do not refresh at the instruments usual rate or when the instrument is sampling clean air. If this error occurred, the values were not recorded as a leak, and the instrument was restarted to correct the error. The GS-700 H_2 has shown good accuracy against a range of hydrogen concentrations with a likely reliable detection limit of 10 ppm, which is comparable to its accuracy for natural gas.

3.2 Leak rate quantification

Leak rate quantification was achieved using a high flow sampling (HFS) technique. The technique involves loosely encapsulating the leak, drawing the leak and excess air through an instrument at an induced, measured flow rate and recording the target gas concentration within the induced flow. The leak rate of the target gas is then calculated directly from the induced flow rate and the gas concentration.

The HETEK Flow Sampler (HETEK) is a HFS instrument designed for the quantification of hydrocarbon leaks. The HETEK simultaneously measures the induced sampling flow rate and the hydrocarbon concentration in the induced flow and calculates the hydrocarbon leak rate. It is not, however, sensitive to hydrogen. In this work the HETEK was used only to generate and measure the induced sampling flow and capture the leak. The hydrogen and hydrocarbon concentrations in the induced sampling flow were measured simultaneously using the GS-700 H_2. This was achieved by inserting the inlet of the GS-700 H_2 into the exhaust of the HETEK. In this configuration the two instruments are integrated with the HETEK providing the leak capture and measuring the induced sample

flow rate and the GS-700 H_2 measuring the gas concentrations in the induced sample flow. This arrangement was tested at NPL prior to the measurements and shown to perform comparably to a methodology utilising the Bacharach Hi-Flow Sampler as the HFS system.

Testing of the HFS methodology found that only the peak concentrations recorded by the GS-700 H_2 during leak quantification corresponded well with the true leak rate. This agrees with the theory that lower concentrations are caused by incomplete leak capture. In this work, however, where the ratio of the leaking gases is of more importance than the magnitude, simultaneous measurements have been prioritised. During the quantification of the leaks the peak concentration of hydrogen occurred simultaneously with the peak concentration of hydrocarbons, where the measurement was above the detection limit of the instrument.

4. Results and Discussion

Table 4.1 reports the results of the initial screening of the leaks where the concentrations of the gases were recorded at the leak interface. Of the 9 leaks originally selected for measurement only 6 were found to still be present. Where applicable the H_2:HC concentration ratio is reported along with the difference to the reported process gas ratio at the time of the measurement.

Table 4.1 Summary of initial leak screening results.

No.	Leak ID	Component ID	Component Type	Hydrocarbon concentration (ppm)	Hydrogen concentration (ppm)	Measured H_2:HC concentration ratio	Reported process gas H_2:HC ratio	% difference
1	25npl14	LAN03010	Plug	1225	939	0.77 ± 0.06	0.40	63%
2	25npl15*	LAN03010	Plug	25	54	2.16 ± 1.13	0.40	138%
3	25npl11	No ID	Plug	1750	1638	0.94 ± 0.07	0.39	83%
4	25npl30	NG:A1	Valve stem	17960	6015	0.33 ± 0.03	0.82	-84%
5	25npl32	P13	Valve stem	4800	2513	0.52 ± 0.04	0.82	-44%
6	25npl35	No ID	Plug	23920	-		0.23	-

*non-simultaneous measurements.

The hydrogen and hydrocarbon concentration values reported in Table 4.1 for leak ID 25npl15 are non-simultaneous. All other measurements are simultaneous. For this leak, at any one time, only hydrogen or hydrocarbon gas concentration was recorded. The H_2:HC concentration ratio reported is for indication only were the measurements simultaneous and may not represent the actual ratio of the leaking gases and it is notable that this is the greatest difference to the reported gas ratio. The hydrogen measurements have been corrected for the calibration performed prior to the campaign with an uncertainty assigned arising from the calibration. The full range of the hydrocarbon response was not fully calibrated. A single point calibration check was conducted which showed a difference of up to 3% of the value. The hydrocarbon values have not been corrected but an uncertainty of 3% has been assigned. The uncertainty in the gas ratio is the propagation of the uncertainty in the hydrogen and hydrocarbon concentration measurements and expanded using a coverage factor of k=2.

Table 4.2 reports the leak rate quantifications of hydrogen and hydrocarbon for each of the leaks along with the leak rate H_2:HC ratio where applicable.

Table 4.2 Summary of leak rate quantifications.

No.	Leak ID	Sampling flow rate (l/min)	Hydrocarbon concentration (ppm)	Hydrogen concentration (ppm)	Hydrocarbon leak rate (l/min)	Hydrogen leak rate (l/min)	Measured H_2:HC leak rate ratio	Reported process gas H_2:HC ratio	% difference
1	25npl14	165.1	50	45	0.008	0.007	0.91 ± 0.28	0.40	78%
2	25npl15	168.9	-	40	-	0.007		0.40	-
3	25npl11	164.2	-	87	-	0.014		0.39	-
4	25npl30	169.9	700	243	0.119	0.041	0.35 ± 0.02	0.82	-81%
5	25npl32	157.6	1775	1721	0.280	0.271	0.91 ± 0.04	0.82	17%
6	25npl35	158.5	550	-	-	-		0.23	-

For leak ID 25npl35 only a hydrocarbon leak rate was quantifiable which is consistent with the initial concentration screening where only hydrocarbon was measured. For leak IDs 25npl15 and 25npl11 only a hydrogen leak rate was quantifiable. For leak ID 25npl15 this could be expected with the hydrocarbon concentration below the detection limit. It is also notable that the hydrocarbon concentration recorded during the screening phase was only observed for a short period with no hydrocarbons recorded for most of the time. For leak ID 25npl11 it should be expected that a hydrocarbon leak rate could be quantified given the high concentration of hydrocarbon measured during the screening. It is not known why no hydrocarbon concentration was measured during the subsequent quantification measurement whilst hydrogen was.

The target process gas composition was a 20:80 blend of H_2:HC. In practise the site experienced challenges in achieving the desired blend and maintaining a stable mixture. Table 4.3 reports the gas blend reported by the site at the time of each measurement and the corresponding H_2:HC ratio.

Table 4.3 Reported gas composition during each measurement.

Leak ID	Reported gas composition (%)		Reported process gas H_2:HC ratio
	Hydrocarbon	Hydrogen	
25npl14	70	28	0.40
25npl15	71	28	0.40
25npl11	71	28	0.39
25npl30	53	44	0.82
25npl32	53	44	0.82
25npl35	81	19	0.23

The limited set of results obtained do not show a clear preferential emission of hydrogen or hydrocarbon. The measured H_2:HC ratio had a higher hydrogen proportion for some leaks and a higher hydrocarbon proportion for other leaks compared to the reported process gas ratio at the time of the measurement. With approximately equal number of cases either way. The sample size, nor the difference in magnitude of the leaks, is great enough to discern whether the size of the leak influences the likelihood of either gas leaking preferentially.

An explanation for the inconsistency in the results observed could be that the reported process gas ratio is not representative of the internal gas composition at the point of the leak. The hydrogen and hydrocarbon components were introduced to the rig at different locations and the composition measured at dead end locations where it is likely that the mixing was not representative. It could be that the differences are caused by poor internal mixing either by the leak being close to the location of the introduction of one of the gases, where it would be expected for that gas to be a higher proportion of the process gas or on a part of the rig where the geometry was not conducive to complete sample mixing. A recommendation, were the work to be repeated, would be to measure the internal composition at multiple sampling locations and for this to be shown to be stable prior to starting measurements.

5. Conclusions

This report presents the results from a fugitive emissions survey to the National Gas FutureGrid facility at DNV Spadeadam site. The measurements were carried out by NPL on 7th October 2025 and form the deliverables for the National Gas Transmissions Preferential Emissions Survey.

The purpose of this study was to assess, due to the physiochemical differences between hydrogen and methane, whether hydrogen, being a smaller molecule, is preferentially released from leaks within pressured pipework when in a hydrogen:hydrocarbon blend. Simultaneous measurements of the concentration of hydrogen and hydrocarbons were made at each leak such that the emission ratio of the gas concentration could be determined. Additionally, the emission rates of both gases were quantified simultaneously with the ratio of the rates calculated. The calculated emission ratios could then be compared to the source gas blend ratio.

The aim in this project was to revisit emission sources previously identified in January 2025 as part of a separate project. At that time the facility was running with 100% hydrogen as the process gas. The emission sources proposed for inclusion in this project took account of the reduced hydrogen content in the blended process gas and selected where they would be expected to be above the detection limit.

In total six emissions were measured with a percentage difference between the measured hydrogen:hydrocarbon leak rate ratio and the reported process gas ratio of -81 – 78%. Two leaks exhibited a greater proportion of hydrocarbon in the emitted gas than the reported blends with 4 exhibiting a greater proportion of hydrogen. For two of these leaks only a hydrogen emission rate was quantified although it should be noted that for both leaks both gases were measured during an initial screening of the component.

It was noted that there were challenges in achieving and maintaining the desired hydrogen and hydrocarbon gas ratio within the equipment and that there are potential issues with the mixing of the gases within the equipment. Differences in the measured gas ratio of emissions could arise from poor mixing within the equipment leading to different internal ratios at the point of the leaks. The results from this study did not show a consistent preferential emission of one gas over the other from the blended process gas mix.

Notwithstanding the challenges experienced this study has shown that it is possible to detect and quantify leaks of multi-component gases simultaneously. Further work is required to determine whether preferential emissions are exhibited from industrial process equipment in which it will be necessary to fully characterise the internal gas composition in order to inform an interpretation of the results.

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Preferential Emissions Measurement Survey for National Gas

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PREFERENTIAL EMISSIONS STUDY

Testing Report

National Gas Transmission plc

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Table of contents

1 EXECUTIVE SUMMARY

The Preferential Emissions Study has been carried out by DNV in partnership with National Gas Transmission on the FutureGrid Facility. This study was carried out following the findings of Phase 1 of testing on FutureGrid to investigate whether the concentration of hydrogen in a gas blend causes preferential leakage. The study aimed to assess the change in gas blend composition for static and compressor-driven flow conditions in the FutureGrid facility for a nominally constant pressure (70barg). The gas blends considered for the purpose of this test were 5% and 20% hydrogen/natural gas blends.

The test program was carried out for 4 weeks where the gas blend was actively flowed for week 1 (20% hydrogen/natural gas) and week 3 (5% hydrogen/natural gas) and held under static conditions for week 2 and week 4. The gas quality was continuously measured using a gas chromatograph (every 4 minutes) from a point on the high-pressure flow loop and additional samples were taken from 3 positions considered dead ends (36” North Array, 48” High Pressure Array, and Hays Pressure Reduction Skid) on the facility. The samples from the dead-end locations were taken daily during active flowing weeks and taken at the start and end of testing during the static weeks.

The key finding was that preferential emission of hydrogen in the flow loop was not observed for the 36” and 48” arrays. Additionally, no conclusions can be made about preferential emissions from the Hays skid due to its complex geometry, and existing leak paths. However, the running losses of the compressor; homogeneity of the gas blend; and the geometry of dead-ends/flow loop assets play a key role in the measured gas quality of a blend.

2 INTRODUCTION

The UK government has considered Hydrogen as a potential green energy vector to aid in its commitment to achieving Net Zero Emissions by 2050 and improve the rate of decarbonization in the UK National Gas Transmission System (UK NTS). Considerable investigation has already been undertaken to assess the compatibility of the existing National Transmission System (NTS) infrastructure with hydrogen to inform policy and safety decisions in supporting the transition. The FutureGrid Facility was built at DNV Spadeadam Research and Testing Site, the facility was constructed from a range of decommissioned assets from the national transmission system (NTS) to best represent what is currently installed on the NTS.

Following the asset performance testing carried out on the FutureGrid Phase 1 [1], specific trends regarding the leakage of hydrogen in hydrogen/methane blends were noted but not investigated.

Consequently, this report aims to identify and quantify the trends in gas leakage when hydrogen-methane are transported within the FutureGrid gas flow loop at constant pressure (70barg). The variables being considered for the test program are gas blends (5% Hydrogen and 20% hydrogen) and flow conditions (static and flowing).

3 EXPERIMENTAL SETUP

The test program for investigating preferential emissions of Natural Gas – Hydrogen blends was carried out on the high-pressure flow loop of the existing FutureGrid Facility. Flow around the FutureGrid Test Loop is established by a reciprocating compressor. FutureGrid can be operated in 2 different configurations, the high-pressure flow loop on, which was used for this test programme, and the low-pressure flow loop. Three Sample locations were selected to establish homogeneity of the blended gas across the facility as the pipework configuration is complex.

Figure 1 shows the flow loop for the testing and the locations for the point measurement of gas composition (Appendix A shows further details about the flow loop and assets). A 48” pipe array is located on an off take on the outlet side of the compression unit, which acts as high pressure buffer. A 36” array is located on an off take on the inlet of the compression unit which acts as a low-pressure buffer. Both arrays have no flow through creating dead ends at the furthest extents. These dead ends were expected to influence the mixing of blended gas within the test facility, potentially containing higher or lower hydrogen concentrations, hence these were selected as 2 of the 3 total gas sample locations. Gas sample location A is the furthest extent of the 36” array, C is the furthest extent of the 48” array. Sample point B is the third sample location and is located within the low-pressure flow loop of the facility. This section was not to be used during the project due to requiring lower pressure across the test facility to operate and flow. Due to not flowing through this section, it also serves as a dead end.

A gas chromatograph (Rosemount 700XA) was used to measure gas composition of the 3 collected samples (Appendix B shows the performance evaluation certificate). Additionally, the same gas chromatograph automatically sampled gas from a single point in the loop every 4 minutes. This continuous sample point is located on the straight section of the West side of the test facility. The gas concentrations measured by the GC are n-Hexane, Propane, i-Butane, Neopentane, i-Pentane, n-Pentane, Methane, Carbon Dioxide, Ethane, Hydrogen, and Nitrogen. The focus of this study is on the Methane and Hydrogen concentrations.

Figure 1 – Continuous gas sample location and individual sample measurement point locations

The test programme consisted of 2 phases on 2 different blends. A blend consisting of 20% Hydrogen in Natural Gas was actively flowed (70barg) through the loop in week 1 of testing (phase1) followed by a week of static conditions (70barg pressure, no gas flow, phase 2). This was repeated for a 5% Hydrogen/Natural Gas blend which was flowed (70barg) and maintained in static conditions (70barg) for weeks 3 and 4 respectively. The term 'static conditions' refers to the flow loop compressor being turned off and isolated from the rest of the flow loop. The intention behind this is to remove the scope of the compressor's running losses and reduce any sources of inventory loss from the rig.

The blends were achieved by estimation using partial pressures of the gases and Dalton's Law. For a total operating pressure of 70 barg, the partial pressure or the fill pressure of hydrogen required for a 20% blend is 14 barg. Hydrogen was introduced into the test facility via road trailer tankers, supplied at 300 barg, which were offloaded through an existing fill line on the West side of the 48" array, see Figure 1. Natural gas was introduced into the test facility from Spadeadam site cryogenic services where LNG was vapourised and Natural gas was pumped directly into the FutureGrid test facility, via a connection point on the East end of the 48" array. The 5% blend of hydrogen was achieved by method of dilution and using the same approach of partial pressures. The facility was vented down to ~17.5 barg and the resulting gas mixture was diluted with natural gas back up to 70 barg.

The operating envelope of the FutureGrid facility is shown below in Table 1. These limitations are imposed by the recompression unit and relate to alarm points and shutdowns.

Table 1: FutureGrid Operating Limits

Parameter	Minimum	Maximum
Pressure	44 barg	70 barg
Temperature	5 ºC	40 ºC
Flowrate	5,000 SCMH	68,500 SCMH

The temperature the facility operates at is subject to ambient conditions as no temperature control is available, except for an after cooler within the recompression unit. Temperature was not specified for this test programme.

Testing was to start at a fill and equalisation pressure of nominally ~67-68 barg. This is due to the facility operating with a 2-3 barg pressure differential between the upstream and downstream sections of the compression unit. This allows for an outlet pressure of 70 barg from the compressor. This pressure was allowed to decay during the flowing weeks where the compressor is actively running. Due to the configuration and design of this unit, running losses of gas occur. As in previous test programmes, pressure could be increased by way of introducing more Natural gas or hydrogen, however this would be an additional uncontrolled variable.

Flowrate is controlled on the facility by way of a variable speed drive (VSD) on the compression unit and an internal flow bypass valve (BPV). The initial flowrate selected for the flowing weeks was 30,000 SCMH. This was adjusted throughout the week to allow for dynamic changes across the test facility, such as vibration and noise which are subject to the compression units VSD setting and BPV position.

During the 1-week period of operating the compressor, samples were taken from each of the 3 locations once per day to understand the degree of mixing during agitation of the gas. Following this period, 1-week of static mixing was allowed, where samples were taken twice, once at the start of this period and once at the end. This sampling frequency was repeated for the following test weeks on the 5% blend.

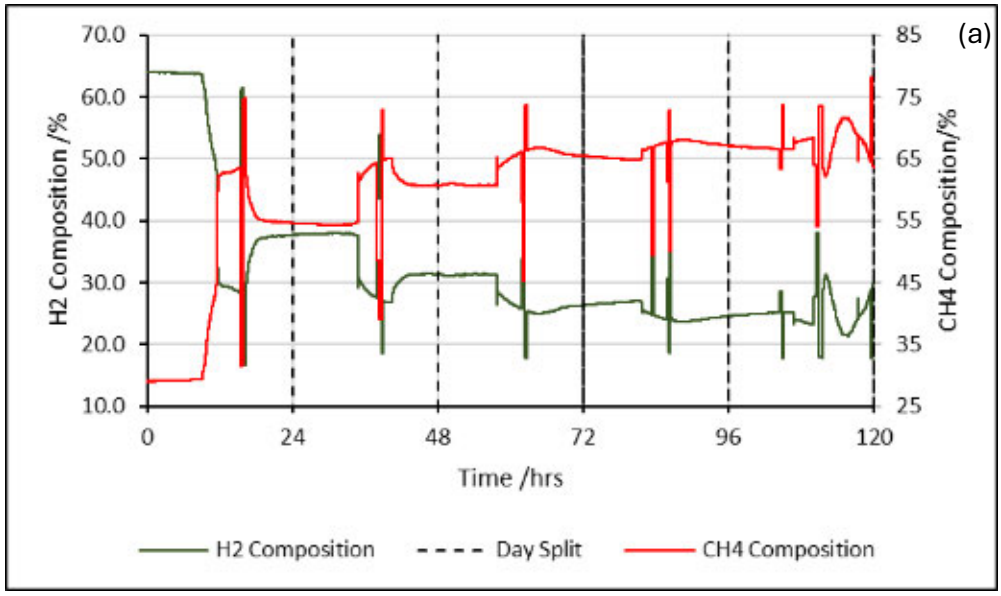
4 RESULTS

This section highlights the change in gas blend concentrations for individual weeks of testing. The gas blend composition was continuously measured from the high-pressure flow loop (Figure 1) using a gas chromatograph (Rosemount 700XA). Individual gas samples collected from different points on the flow loop were analysed on the same chromatograph. Three gas composition readings were recorded for every individual sample, and an average value was calculated for the purpose of this report. Section 4.1 describes the findings pertaining to the flow loop, and section 4.2 focuses on the findings from samples collected at the individual locations.

4.1 Flow loop conditions and Gas-blend Concentrations

4.1.1 Test Week 1

The first week of the test aimed to achieve a 20% hydrogen/natural gas blend by mixing the two gases with the compressor running. Figure 2 shows the gas composition and ambient conditions of the flow loop during the week. Methane concentrations have been considered for the purpose of this report as it is the most abundant species in natural gas.



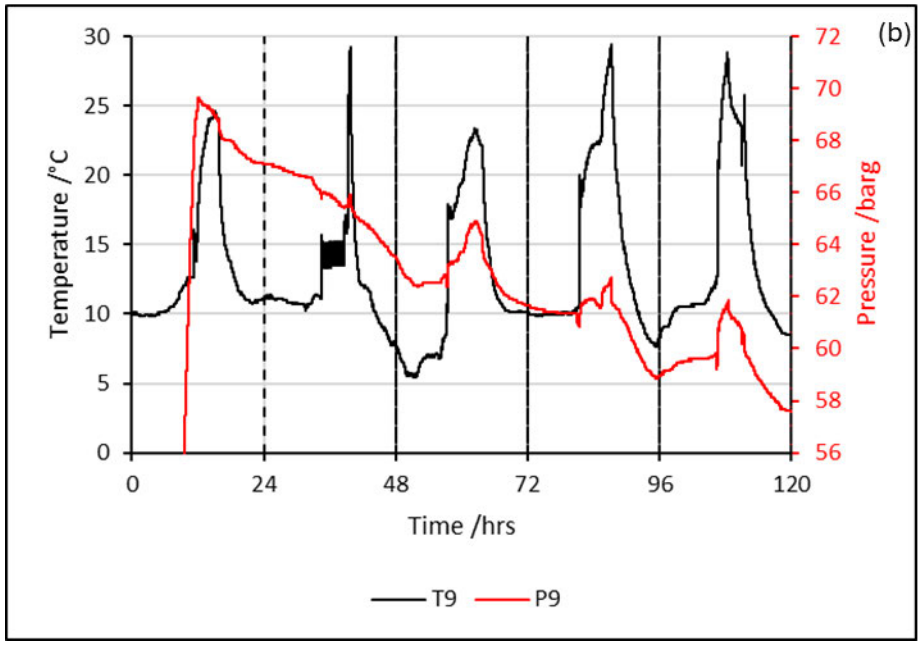


Figure 2 (a) Continuous gas quality measurements for test week 1 (Note: the sharp peaks and drops are individual sample measurements for the dead ends. The odd concentration readings from 108h-120h are due to a human error); and (b) Flow loop pressure and temperature measurement for week 1 of testing

Figure 2a shows the change in concentration of each gas during the week of flowing with the compressor. At the start of the week, a sharp drop in hydrogen concentration (~65%/vol to ~30%/vol) is noted with a corresponding rise in methane concentration (~30%/vol to ~64%/vol) and this can be attributed to the start of the mixing process for the two gases. As the compressor was turned off each day, a rise in hydrogen concentration and consequent drop in methane concentration was observed. The sharp changes in concentrations at the start and end of the day can be attributed to change in the rate of mixing due to start/stop of flow within the loop. As the week progressed, it was noted that the drop in hydrogen concentration (and consequent rise in methane concentration) at the start of the day's flow reduced, thus suggesting a more relatively homogeneous mix as the gases were flowed through the loop. At the start of week 1, the hydrogen concentration was ~30%/vol and the final concentration at the end of the week was ~25%/vol. The corresponding methane concentration was ~64%/vol and the final concentration was ~69%/vol. Table 2 shows the change in flow loop concentrations of methane and hydrogen for each day of active testing, and the estimated rate of change of concentration.

Table 2 Estimation of rate of change in gas concentration in the gas flow loop during Week 1 of testing (06/10/2025 to 10/10/2025)

Testing Day	Change in Gas Concentration		Compressor Running Time (h)	Rate of change in gas concentration (%/h)
	Hydrogen (%vol)	Methane (%vol)		
1	40	40	6	6.67
2	28	28	6.5	4.31
3	6	6	6.5	0.92
4	4	4	6.5	0.62
5	2	2	6.5	0.31

Figure 2b shows the change in temperature and pressure in the flow loop over the course of week 1 of testing. Due to running losses and known leaks on the flow loop, the pressure dropped from ~70 barg to ~58 barg. During the week, fluctuations in ambient temperature resulted in corresponding changes in pressure within the flow loop. As the pressure in the loop reduced during the mixing process, the approximate rate of change in gas concentration reduced as well, further suggesting a relatively stable and homogeneous blend.

4.1.2 Test Week 2

The second week of the test aimed to maintain the hydrogen/natural gas blend in the flow loop under static conditions. Figure 3 shows the gas composition and ambient conditions of the flow loop during the week (Note: The first 10 hours of day 1 should be ignored due to an error with the gas chromatograph sampling process).

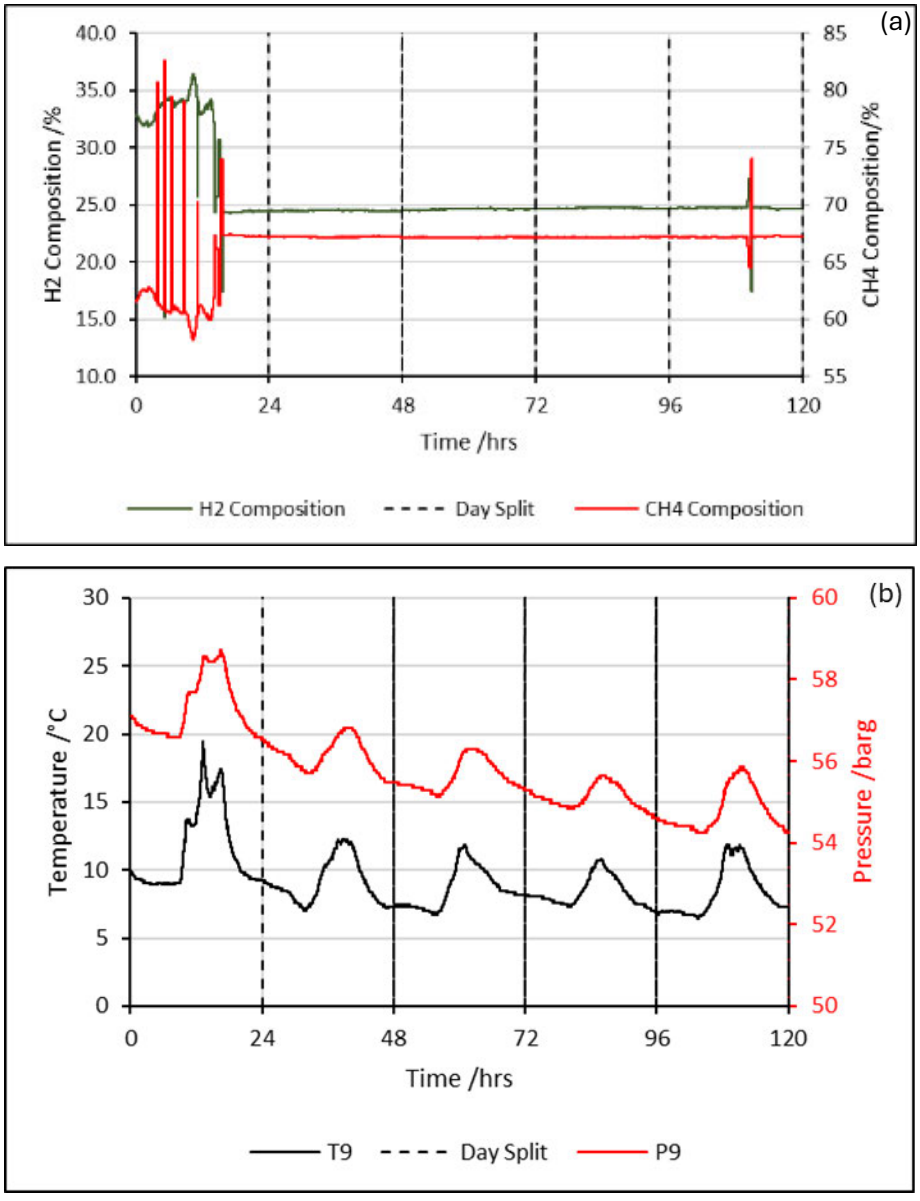


Figure 3 (a) Continuous gas quality measurements for test week 2 from the GC shown in Figure 1 (Note: the sharp peaks and drops are individual sample measurements for the dead ends); and (b) Flow loop pressure and temperature measurement for week 2 of testing

Figure 3a shows the composition of the hydrogen and methane in the flow loop and no significant change in gas concentrations were noted. Figure 3b shows the ambient conditions of the flow loop while the compressor is not running, and a pressure drop from ~57barg to ~54barg was noted over the course of the week. Similar to week 1, the fluctuation in ambient temperature resulted in corresponding pressure fluctuations in the loop. The drop in pressure is due to known leaks

in certain sections of the flow loop. However, the lack of change in measured methane and hydrogen concentrations suggests that preferential emissions do not occur.

4.1.3 Test Week 3

The third week of the test aimed to achieve a 5% hydrogen/natural gas blend by mixing the two gases with the compressor running. Figure 4 shows the gas composition and ambient conditions of the flow loop during the week.

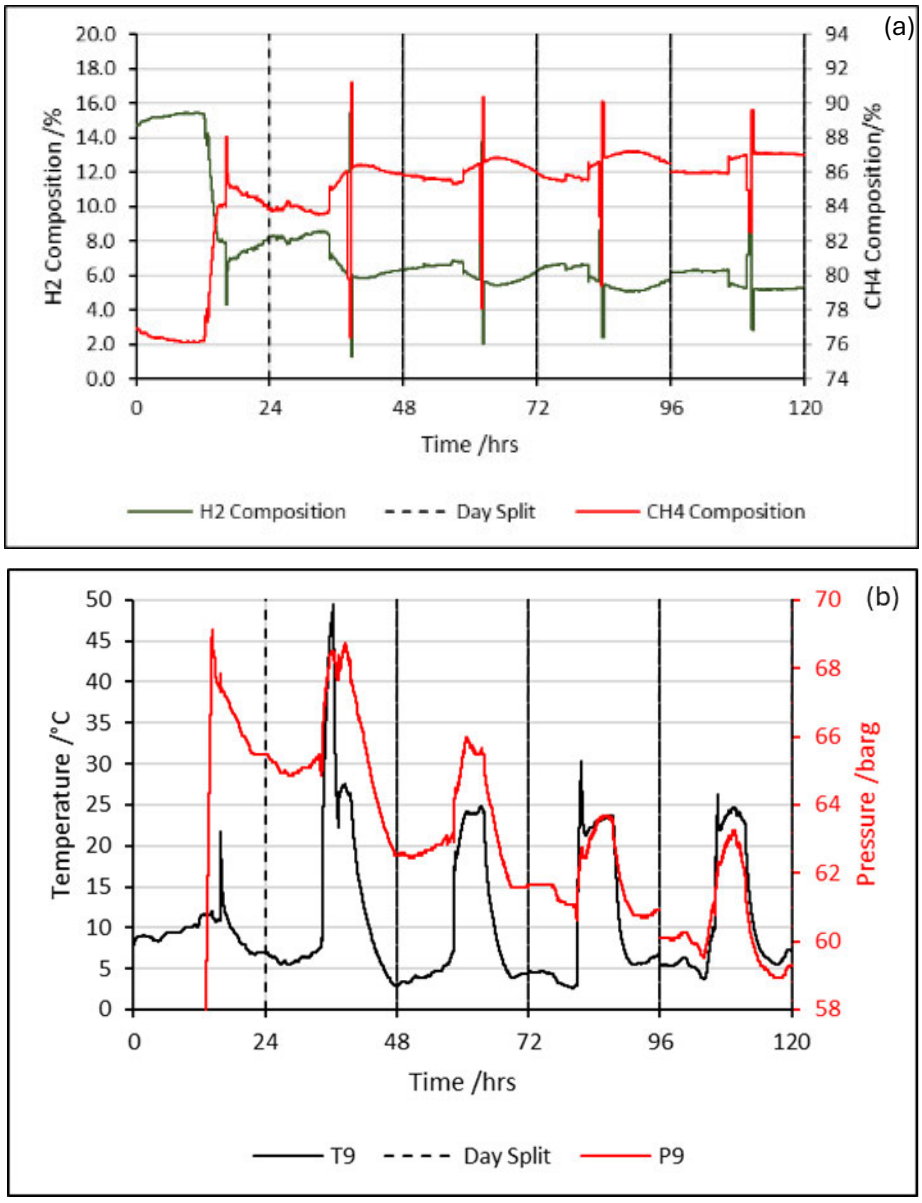


Figure 4 (a) Continuous gas quality measurements for test week 3 (Note: the sharp peaks and drops are individual sample measurements for the dead ends); and (b) Flow loop pressure and temperature measurement for week 3 of testing

Figure 4a shows the concentration of the gases as the compressor was used with the flow loop to achieve the required blend. Even at lower concentrations, a sharp change in hydrogen (~15%/vol to ~8%/vol) and methane (~77%/vol to ~84%/vol) concentrations was observed when the compressor was started on day 1 of testing. This trend in gas concentration change was similar to the observations during the week 1 of testing with the 20% hydrogen blend. However, as the week progressed, the rate in reduction of hydrogen concentration (and corresponding rise in methane concentration) reduced, which is suggestive of a homogeneous blend (~5.4%/vol Hydrogen and ~88%/vol Methane). Table 3 shows the change in flow loop concentrations of methane and hydrogen for each day of active testing, and the estimated rate of change of concentration.

Table 3 Estimation of rate of change in gas concentration in the gas flow loop during Week 3 of testing (21/10/2025, 22/10/2025, 23/10/2025, 24/10/2025, and 27/10/2025)

Testing Day	Change in Gas Concentration		Compressor Running Time (h)	Rate of change in gas concentration (%/h)
	Hydrogen (%vol)	Methane (%vol)		
1	8	8	6	1.25
2	2.5	2.5	6.5	0.38
3	1.3	1.3	6.5	0.20
4	1.5	1.5	6.5	0.23
5	0.8	0.8	6.5	0.12

Figure 4b shows the ambient conditions of the flow loop during gas flow with 5%/vol blend of hydrogen/natural gas. Like week 1 of testing, the running losses of the compressor resulted in a pressure drop of 10barg (from ~69 barg to ~59 barg). The fluctuations in flow loop pressure during the testing week were consistent with the fluctuations in ambient temperature. It must be noted that the sharp drop in pressure between day 4 and day 5 of testing was due to a 2-day gap in the compressor's running which has not been reported.

4.1.4 Test Week 4

The fourth week of the test aimed to maintain the hydrogen/natural gas blend in the flow loop under static conditions. Figure 5 shows the gas composition and ambient conditions of the flow loop during the week.

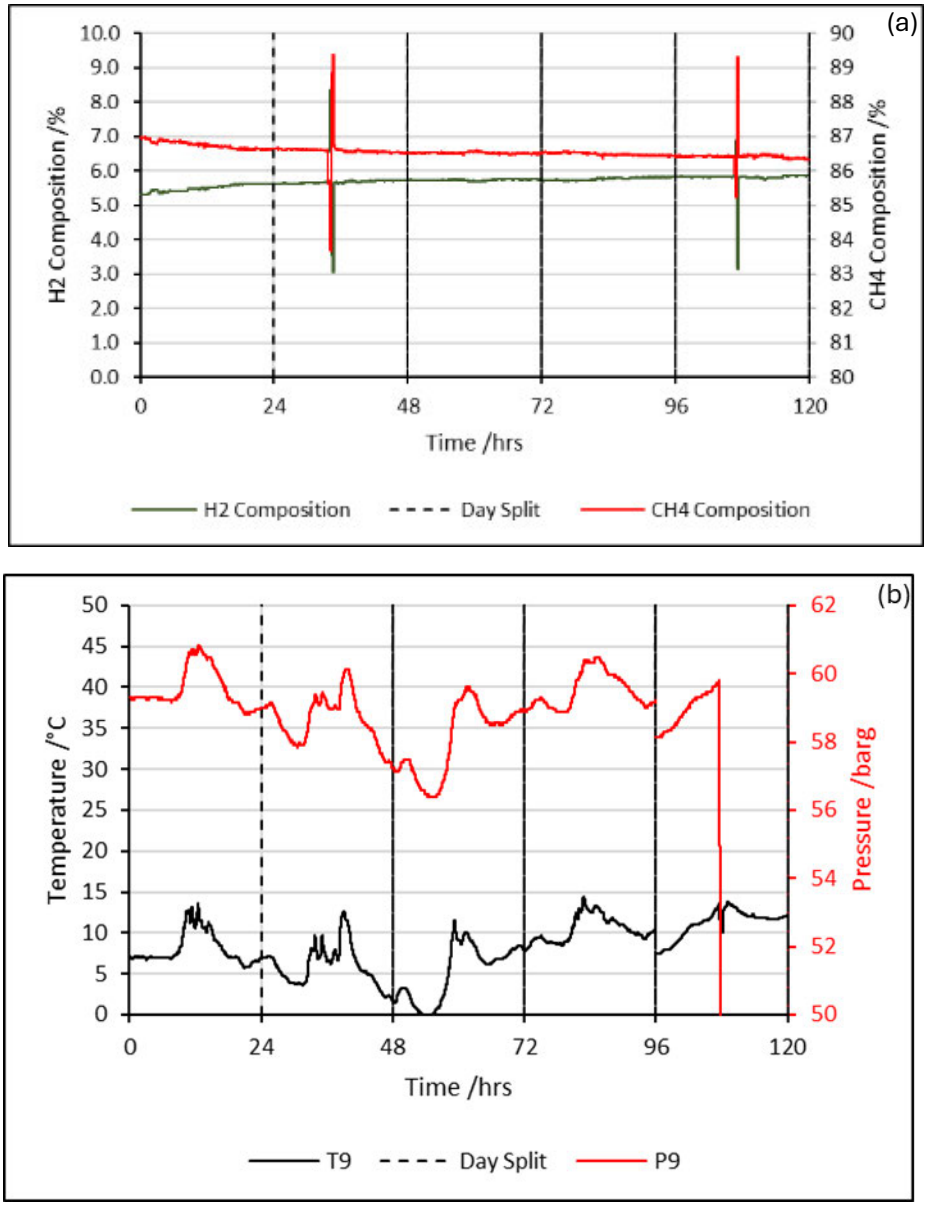


Figure 5 (a) Continuous gas quality measurements for test week 4 (Note: the sharp peaks and drops are individual sample measurements for the dead ends); and (b) Flow loop pressure and temperature measurement for week 4 of testing

From Figure 5a, the concentration of hydrogen in the gas blend remained constant at ~5%/vol, and the methane concentration was ~87%/vol. Figure 5b showed no significant loss in pressure for the fourth week of testing and pressure

fluctuations were coherent with the ambient temperature fluctuations. The findings from static test conditions suggest that no preferential leakage was noted from the wider flow loop.

4.2 Gas sample analysis at specific locations

This sub-section looks at the gas compositions measured at the various dead ends in the flow loop during the different phases of testing in the 4-week period. The samples were taken daily during weeks of compressor-driven flow and taken at the start and end of testing during the static phases of testing.

4.2.1 Test Week 1

Figure 6 shows the gas concentrations for samples taken from the 36" North array; Hays pressure reduction skid; and the 48" high pressure array during week 1 of testing. The compressor was being used to flow the gas blend around the loop with the aim of achieving a 20% hydrogen/natural gas blend.

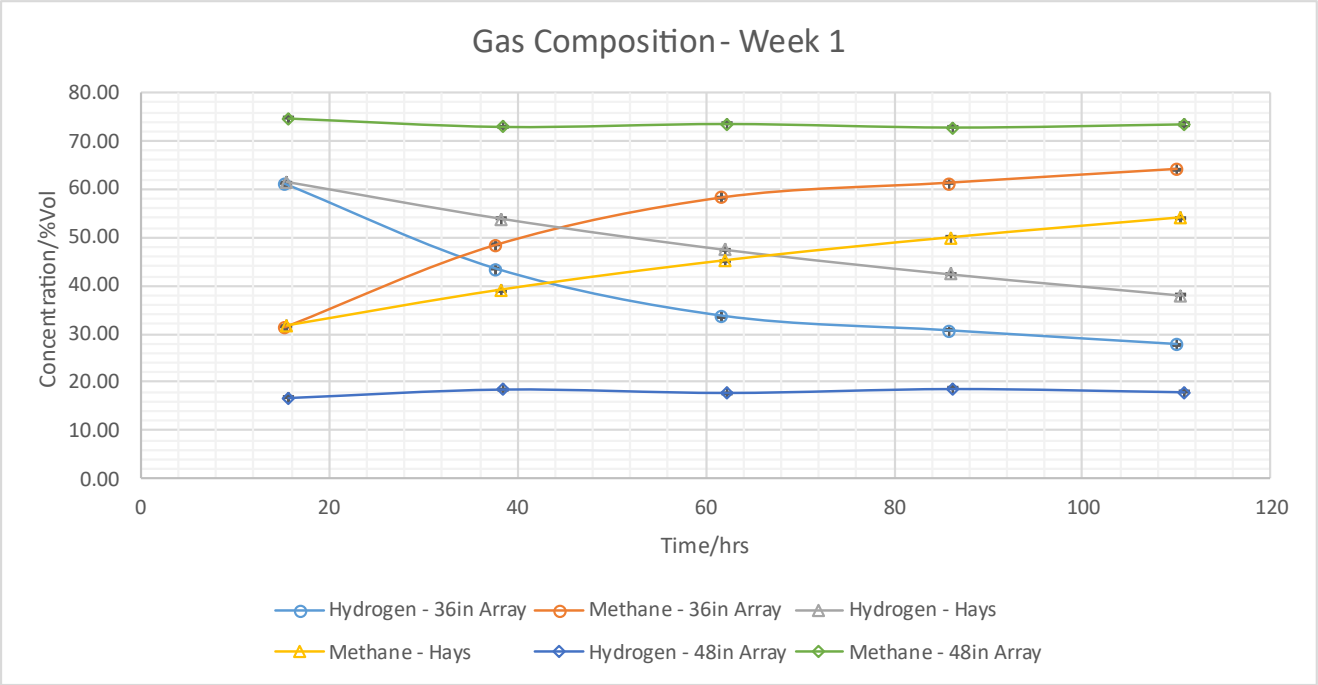


Figure 6 Gas quality measurements for individual locations during test week 1

From Figure 6, the concentrations of hydrogen (~18%/vol) and methane (~75%/vol) in the high-pressure (48") array showed minimum fluctuation over the week of testing. For the 36" array, the initial hydrogen and methane concentrations were ~60%/vol and ~30%/vol respectively. At the end of the week of flowing, the hydrogen and methane concentrations were ~28%/vol and ~63%/vol respectively. Furthermore, at the start of the test week, hydrogen and methane concentrations in the Hays skid were ~61%/vol and ~30%/vol respectively. At the end of the week, the hydrogen and methane concentrations in the Hays skid were ~38%/vol and ~53%/vol respectively. For the Hays skid, and 36" array, the inverse relationship between the hydrogen and methane concentrations was suggestive of a progression in the homogeneity of the gas blend. This was not observed in the 48" array as both gases were off-loaded into this array, thus aiding the blending process at this location. Additionally, the relatively higher hydrogen concentration (and consequently lower methane concentration) in the Hays skid can be attributed to reduced mixing and larger gas losses at that location.

4.2.2 Test Week 2

Figure 7 shows the change in gas concentrations for the 3 sample locations for the second week of testing. The flow loop was held under static conditions with the compressor not operating.

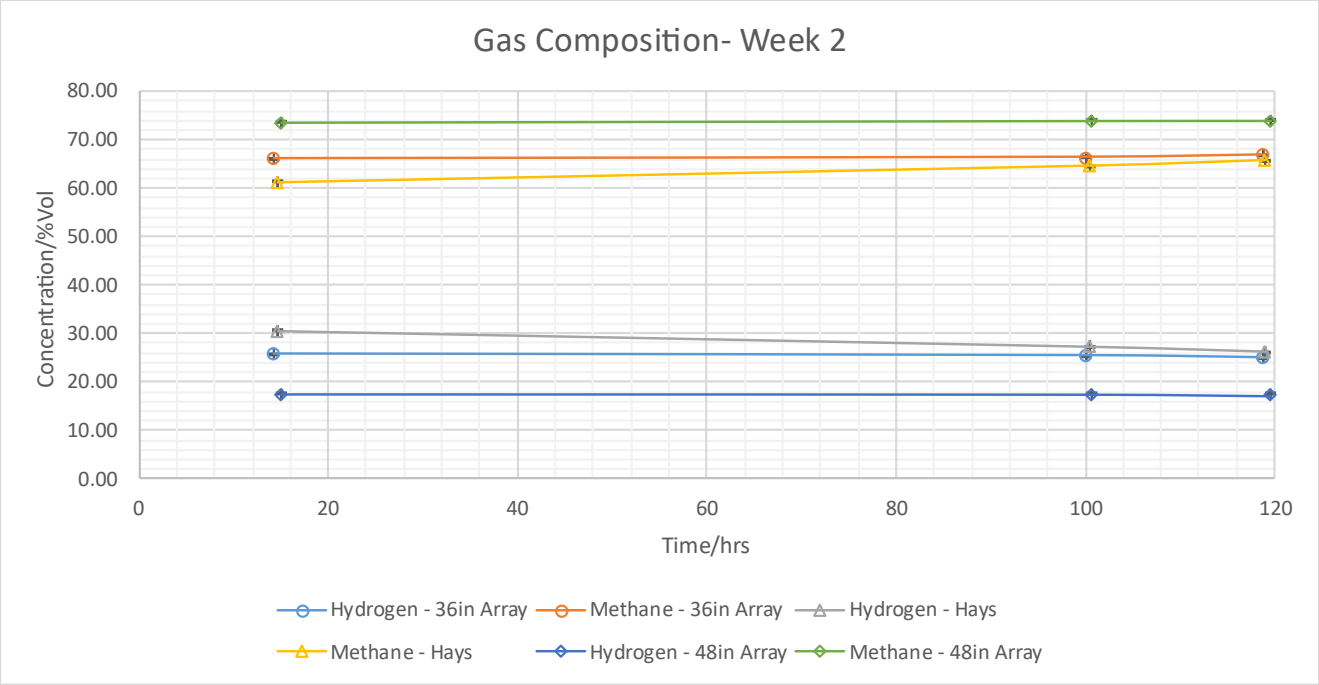


Figure 7 Gas quality measurements for individual locations during test week 2

From Figure 7, the primary observation was the ~3%/vol drop in hydrogen concentration and a similar rise in methane concentration in the Hays skid. Additionally, no significant changes (<0.5%/vol) in hydrogen and methane concentrations were noted for the samples taken from the 36" and 48" arrays. The relatively large change in concentration in the Hays skid can be attributed to known leaks on that section of the flow loop and the lack of homogeneity in the blend from the previous week of testing. The complex geometry of the Hays skid, combined with the lack of active flow through that part of the flow loop make it tougher for the gas to mix in the section. Due to the lack of evidence to suggest either homogenous mixing or stratification of the gases, combined with the multiple leak paths on the skid, it can not be conclusively determined if there is any preferential emission from that sample point. However, the 36" and 48" arrays have no measured leak paths and the corresponding samples do not suggest any preferential emissions.

4.2.3 Test Week 3

Figure 8 shows the gas concentrations from the individual samples during week 3 of testing. This week of testing aimed to blend the gas to a 5% hydrogen/methane blend with the compressor running. The samples were taken daily starting from the second day of the week as the vent and fill from the first two weeks of testing was completed on day 1.

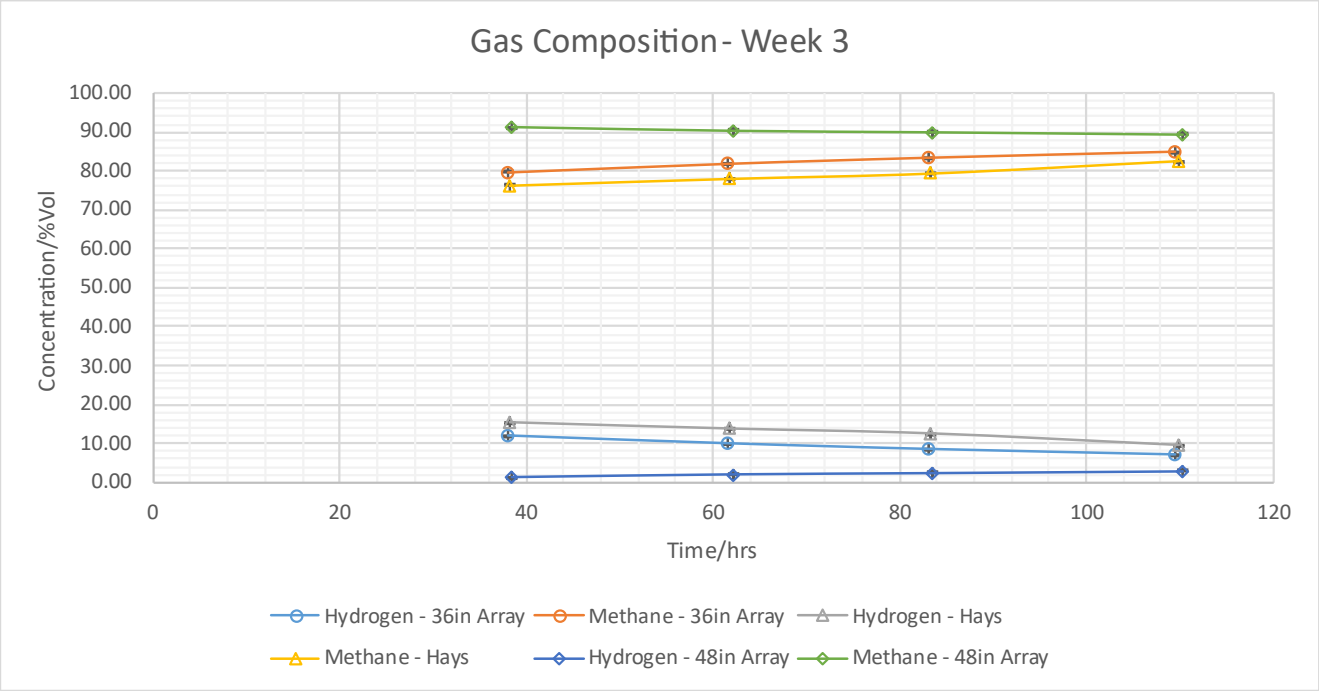


Figure 8 Gas quality measurements for individual locations during test week 3

From Figure 8, similarities can be seen with findings from week 1 with the reduction in hydrogen concentrations and converse increase in hydrogen concentrations for the various sample locations. For the 48" array, the hydrogen concentration rose from ~2%/vol to ~5%/vol while the methane concentration dropped from ~92%/vol to ~89%/vol. Given that this array is the fill location for the loop, the rise in hydrogen concentration as the week progressed can be accepted. The change in hydrogen (~12%/vol to ~8%/vol) and methane (~80%/vol to ~84%/vol) in the 36" array can be explained by the continuous flow of gas through the loop over the course of the week. There was an ~6%/vol change in the samples collected from the Hays skid, that can be explained by the initial lack of blending in the dead end. Given the known leaks in the flow loop and running losses of the compressor, no clear signs of preferential leaks were noted.

4.2.4 Test Week 4

Figure 9 shows the change in gas concentrations for the 3 sample locations for the fourth week of testing. The flow loop was held under static conditions with the compressor not operating.

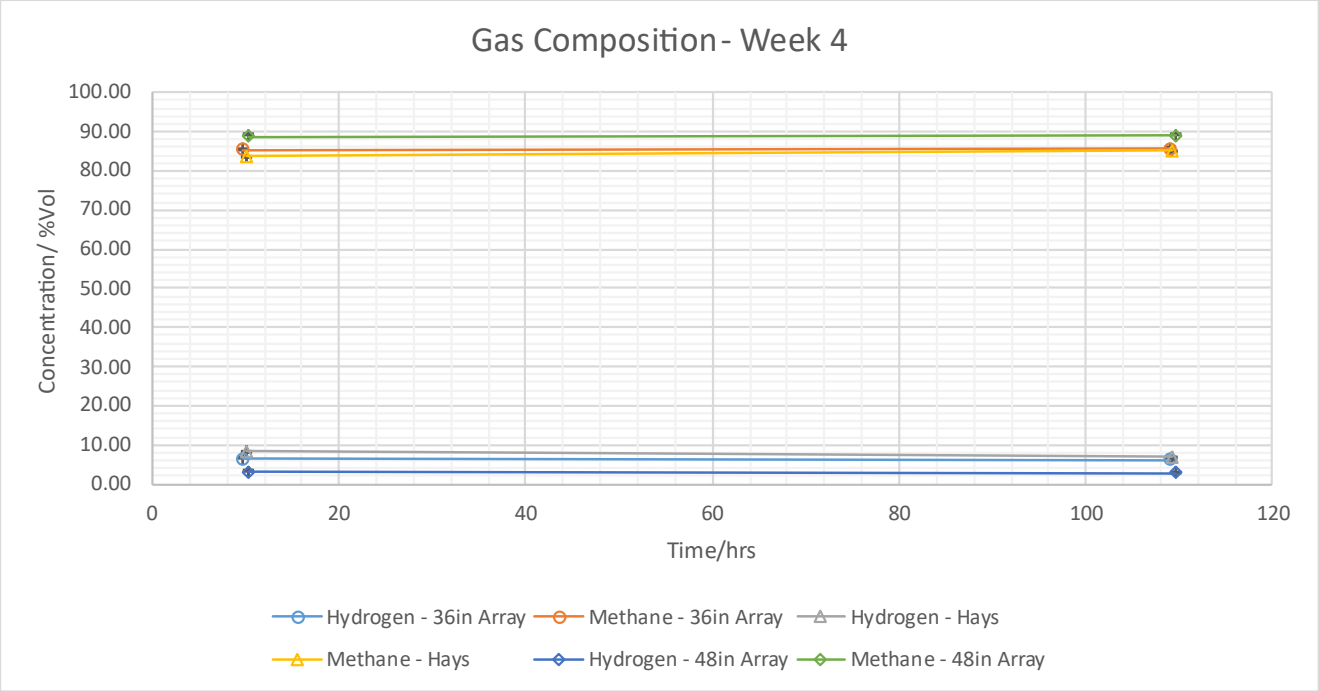


Figure 9 Gas quality measurements for individual locations during test week 4

From Figure 9 it was noted that there was <0.5%/vol change in gas concentrations of methane and hydrogen for the 36" and 48" arrays. There was ~1%/vol change in hydrogen and methane concentrations in the Hays skid during the static week of testing. This change can be explained by the known leaks on the Hays skid, and the relative lack of mixing in that specific dead end on the flow loop.

5 Conclusions

The findings from the study are inconclusive in confirming the occurrence of preferential emission of hydrogen from the flow loop under static or flowing conditions. However, some correlations can be made between the relative homogeneity of the gas blend, the geometry of sampling locations, and the potential for preferential emission of hydrogen from a hydrogen/natural gas blend. For conditions when the gas is well mixed, and there are minimal leakage paths for the gas blend, there is no evidence of preferential emissions. While no evidence of preferential emissions was noted in the wider flow loop during continuous sampling, similar patterns were observed for the 36” and 48” arrays. The 36” and 48” arrays are both assets with a simple geometry and have minimal leak paths, which allow the gases to blend without any leakage in the process. Based on this information, and the measured concentrations from these locations, no evidence of preferential emissions was noted.

For the Hays skid, the gas blends were not homogeneous, and the specific drop in hydrogen concentration was noted. Specific focus and further work is required to understand leakages in the Hays skid. Given its complex geometry, known leak paths, and location in the flow loop (as a dead end), it can’t be concluded whether it preferentially leaks. Furthermore, under static conditions, the dead ends with better mixes (blends similar to those on the main flow loop), and relatively simpler geometries (36” and 48” arrays) showed no significant change in individual gas concentrations.

6 REFERENCES

/1/ DNV Services Ltd., “Asset Performance Testing in a Hydrogen Environment,” DNV Services Ltd., 2024.

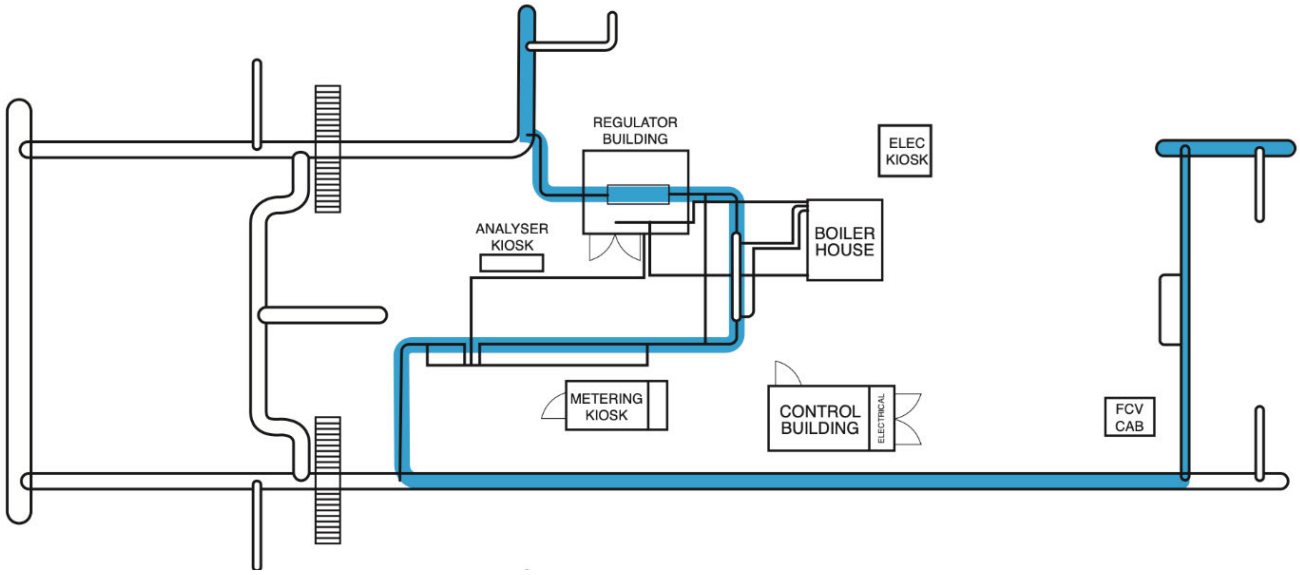
[redacted]

[redacted]

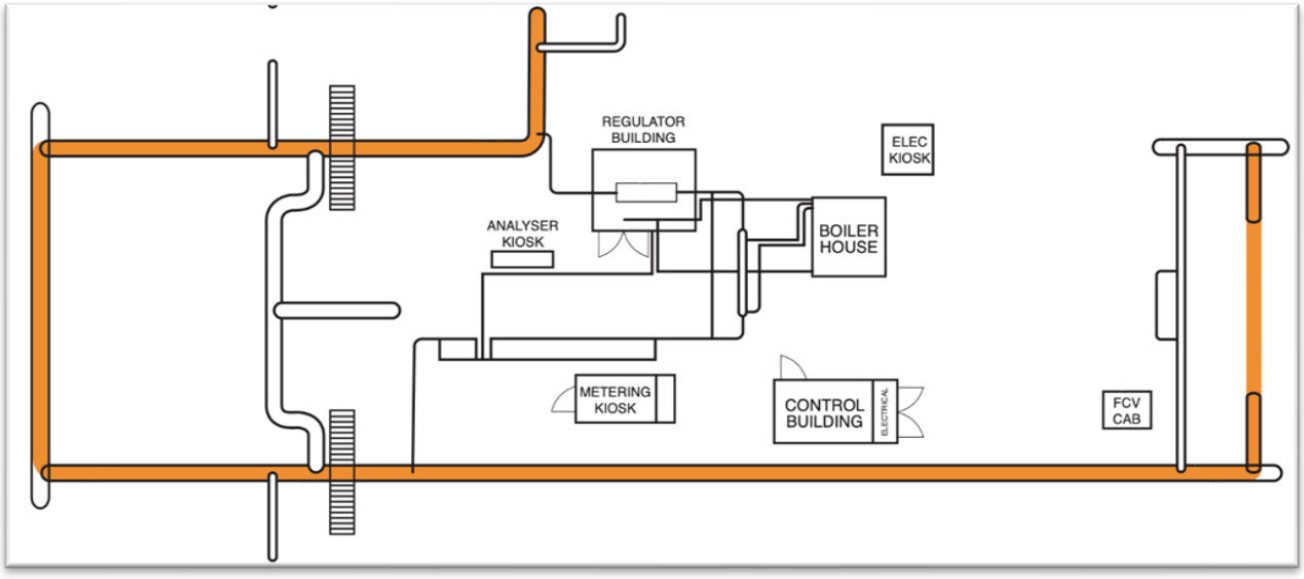
[redacted]

Details of individual assets on FutureGrid Flow Loop

[redacted]



Appendix A Fig 2 FutureGrid low pressure flow loop



Appendix A Fig 3 FutureGrid high pressure flow loop

8 APPENDIX B Performance Evaluation Certificate of Gas Chromatograph

CERTIFICATE OF CALIBRATION

Page 1 of 4

Approved signatory
Name: **Leon Kashap**
Signature

Issued by **EffecTech**
Date of issue **11 August 2023** Certificate number **23/0810/01**

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Customer	: National Gas Transmission National Grid House, Warwick Technology Park, Gallows Hill, Warwick, Warwickshire CV34 6DA
Site	: DNV Spadeadam
Application	: Network entry gas quality measurement
Instrument	: Rosemount 700XA
Serial number	: UKXA2D123
Calibrated by	: Daniel Johnson
Frequency of calibration	: EffecTech recommends this instrument is recalibrated on an annual basis.
Calibration method	: The gas chromatograph was calibrated in accordance with ISO 10723:2012 - *Natural Gas - Performance Evaluation for Analytical Systems* using a set of reference gas mixtures covering a range of compositions over which the instrument is expected to operate.
Date of calibration	: 04 July 2023

The tables on the following pages in this certificate show the reference values and their uncertainties assigned to each measurand for each gas mixture applied to the instrument during the calibration. Additional columns in each table show the measured values reported by the instrument on an *as-found* basis plus errors in both absolute and relative terms.

The reported expanded uncertainty on the reference values for each measurand is based on a standard uncertainty multiplied by a coverage factor k=2, which for a normal distribution provides a level of confidence of approximately 95%. The uncertainty evaluation has been carried out in accordance with JCGM 100:2008 - *Evaluation of measurement data - Guide to the expression of uncertainty in measurement* (GUM).

Components/quantities marked ⋆ are not UKAS accredited as they lie outside the scope of accreditation for our laboratory

EffecTech is accredited by UKAS to undertake the calibration presented in this certificate according to ISO/IEC 17025:2017.	This certificate is issued in accordance with the laboratory accreditation requirements of the United Kingdom Accreditation Service. It provides traceability of measurement to the SI system of units and/or to units of measurement realised at the National Physical Laboratory or other recognised national metrology institutes. This certificate may not be reproduced other than in full, except with the prior written approval of the issuing laboratory. The activities reported were performed at the location of the customer site identified in this certificate

Appendix B Fig 1 FutureGrid Gas Chromatograph certificate of calibration and performance

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